Compound Chondrule Formation in Shock-Wave Heating Model

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Chondrules are 0.1-1 mm-sized spherical silicate objects in chondrite meteorites. It is considered that chondrules were formed in the protoplanetary disk by flash heating; they were heated, melted, and rapidly resolidified. However, the temperature of the protoplanetary disk is not high enough to melt silicate material. Thus, some transient heating processes should be present to melt silicate material and form chondrules. Though the chondrule forming heating process has not been revealed yet, it is thought that the shock-wave heating mechanism is a promising model.

Shock wave heating mechanism works as follows: when a shock wave is present in the protoplanetary disk, the gas pressure accelerates the gas behind the shock front, while the dust particles are not. Thus, the relative velocity between gas and dust particles is generated, and it causes the gas drag heating on the dust particle. This mechanism can explain many features of chondrules; rapid heating and melting, appropriate cooling and resolidifying, chondrule sizes, and 3-dimensional shapes of chondrules.

There are some compound chondrules, which consist of two independent chondrules. A number ratio of them to single chondrules is about 5 %. The compound chondules are thought to be formed by collision of two molten particles. To reveal the formation process of compound chondrules is important to understand the chondrule formation itself. However, previous work on the compound chondrule formation was very limited. Almost no work based on the shock-wave heating model is present. In this study, we examine the compound chondrule formation process in detail in the framework of the shock-wave heating model.

To collide two particles and coalesce together, some physical quantities should meet appropriate conditions. For example, a product of the particle number density, the relative velocity, the cross section, and the elapsed time becomes the number of collisions. Or, if the relative velocity is too large, the collision leads to destruction. Taking into account these effects, we examine the chondrule formation process in the shock-wave heating model.

The particle number density and the velocity of precursor dust particles entering from the pre-shock region (here, we call those particles as the primary particles) are mainly determined by the deceleration due to the gas drag in the post-shock region. The velocity of the particle depends on the particle size. If the sizes of two particles are different each other, the relative velocity between them could be as large as several km/s. In this case, the collision would become destruction (Nakamoto & Miura 2004). On the contrary, if they collide with the small relative velocity, the collision could lead to compound chondrule formation.

Next, we consider processes the particle number density in the post-shock region is enhanced. The primary particles could be destructed mechanically by the ram pressure in the post-shock region. And the partially molten part of the particle would be stripped off. In addition, the collisional destruction between primary particles could happen. Those processes generally produce many dust particles, which we call here secondary particles. Then, the number density is enhanced locally. Moreover, the relative velocity among these secondary particles and between the primary and secondary particles could be small enough. Thus, it is expected that the collision between secondary particles and the primary and the secondary particles should take place and should form compound chondrules.

Phenomena introduced above are complicated. So, it is not easy to precisely estimate the probability of compound chondrule formation, but it is possible to evaluate its orders of magnitude based on the shock-wave heating model. According to our estimation, it seems likely that the compound chondrules can be formed in the shock-wave heating model.